ACTIVE SAFETY OF TRUCKS AND ROAD TRAINS WITH WIDE BASE SINGLE TYRES INSTEAD OF TWIN TYRES

Dr.-Ing. Klaus-Peter Glaeser
Federal Highway Research Institute, BASt
Germany
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1 ABSTRACT

The development of tyre- and truck- manufacturers leads to the direction to introduce wide base single tyres (size 495/45R22,5) instead of twin tyres on the driving axle of trucks, tractors and busses. To study the driving behaviour and safety of various trucks and units with different tyre combinations and loading conditions was the aim of the study.

A computer-aided simulation was used for this investigation. Drive tests with the a 40 t unit with prototype single tyres on the drive axle were carried out to verify the simulation.

Alterations in driving behaviour and driving safety are mainly dependent on the tyre cornering stiffness. The prototype wide single tyres had a higher lateral stiffness which leads to a higher degree of under- steering (safer driving behaviour). The altered spring base on the drive axle had no influence on the side- tilt stability of vehicle combinations but the solo truck profited from the higher rear axle roll stiffness (less danger for roll-over accidents). As far as the driving safety is concerned nothing speaks against wide base tyres on the drive axle. The simulation of a tyre defect in a bend (assuming 40% of the max. transferable side force for the flat tyre) showed no increased danger using wide single tyres.

Later driving tests showed however the need of tyre run flat possibilities to avoid jack-knifing of road trains. Also tyre pressure monitoring systems and electronic stability programs for the trucks are advised.

2 INTRODUCTION

In 2003 several tyre manufacturers came with wide base single tyres for the drive axles of heavy trucks on the European market.
Already in 1996 the European Commission started the COST[1] Action 334 „Effects of Wide Single Tyres and Dual Tyres“ for trucks. The main objective of the action was to establish the relative effects of wide base single tyres and dual tyre assemblies in respect of road pavement damage, vehicle operating costs, vehicle safety, vehicle comfort and environmental aspects (e. g. tyre/road noise).

This paper only describes the vehicle safety aspects. The practical research work (mathematical simulation of the truck driving behaviour) was carried out by order of BASt by the former Institute of Automotive Engineering of the University of Hanover [1] and was part of the German input to the COST 334 Action, which was finished with the presentation of the results on a special workshop on the 7th Symposium on Heavy Vehicles Weights and Dimensions in Delft in June 2002 [2, 3].

3 AIM OF THE STUDY

Cost-reducing aspects such as a lower purchase price and reductions in empty weight and rolling resistance have promoted the use of wide single tyres on the **towed axles of trailers and semi-trailers**.
The development of tyre industry together with the truck manufacturers, which could be seen at the Hanover Motor Show 2002, goes in the direction to introduce wide base single tyres with a tyre width of nearly half a meter (size 495/45R22,5) instead of twin tyres also on the **driving axle of trucks, tractors and busses**, see figure 1.

Figure 1: Wide Base Single Tyres

To study the driving behaviour and safety of various trucks and units with different tyre combinations and loading conditions was the aim of the study.

[1] COST = EUROPEAN COOPERATION IN THE FIELD OF SCIENTIFIC AND TECHNICAL RESEARCH

4 METHODOLOGY

In this research project a **computer-aided simulation** in ADAMS[2] was used to investigate and compare the driving behaviour and driving safety of heavy goods vehicles with wide single tyres on their driving axles on the one hand and standard vehicles with twin tyres on the other. The different tyre widths also enabled alterations to be made to the vehicle's chassis, e. g. changes in the frame width, the spring suspension width and the stabiliser setting.

The following practically-relevant scenarios were simulated:

- keeping the same drive axle (width), only alteration of the different tyre combinations for the drive axle (smaller rear track width for the single tyre) incl. alteration to tyre characteristics, tyre mass and tyre inertia moment;

- enlarged axle width (+70 cm) with the same spring suspension width for the single tyre and same outer width;

- enlarged axle width and alteration of the width of the spring suspension and consequent alteration to the roll stiffness while keeping the stabiliser dimensions the same;

- driving behaviour (safety) with a defect tyre (tyre burst) while driving in a bend (danger of jack knifing).

In order to cover as large a range of vehicles as possible, the simulation was used to test a **solo truck** (about 15% of the heavy goods truck fleet > 15 t in Germany), a **truck with draw bar trailer** (about 35 % of the fleet) and a **tractor with semi-trailer** (about 50% of the fleet). Appropriate driving manoeuvres were also selected for the simulation in order to observe driving safety with the different tyre variations. These were in particular:

- Single lane change: looking for offtracking and rearward amplification,
- J-turn (driving in a sharp bend like in a highway exit): looking for stability limits, see figure2.

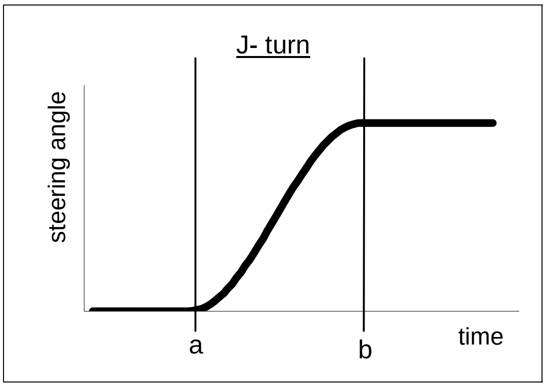


Figure 2: Steering angle vs. time in J-turn test

In the simulation the height of the centre of gravity of the pay load was varied from 1,8 m (like in the driving tests described below), to 2,7 m (centre of volume) and additionally a swinging load hanging from the body's roof (as worst condition for the driving behaviour) was simulated.

Additional **driving tests** (single lane change with the path following method and driving on a circular course) were carried out according to international (ISO) standards with a 40 t **tractor semi-trailer** combination which is the most common variant. These tests were, however, carried out without any alterations to the chassis of the tractor, see figure 3. The tyres chosen were:

- 315/70R22,5 on the steering axle of the tractor
- 315/70R22,5 as twins or 495/45R22,5 as single tyres on the drive axle of the tractor
- 385/65R22,5 as single tyres on the three towed axles of the semi-trailer

These driving test results – carried out by KTI in Hungary - were used to verify the computer simulations. It was assumed that, if the results of this unit are comparable with the results of the simulation of this unit, the solo truck and the truck drawbar-trailer unit are verified, too.

The lateral stiffness (cornering stiffness) of the different tyres were measured by a special measuring truck of the University of Hanover, the wide base 495/45R22,5 super single tyre was measured on a tyre flat-band-test facility by Michelin. The tyre characteristic curves for the single steps in the simulation were taken from calculations with the Delft Tyre Model.

[2] ADAMS = AUTOMATIC DYNAMIC ANALYSIS OF MECHANICAL SYSTEMS

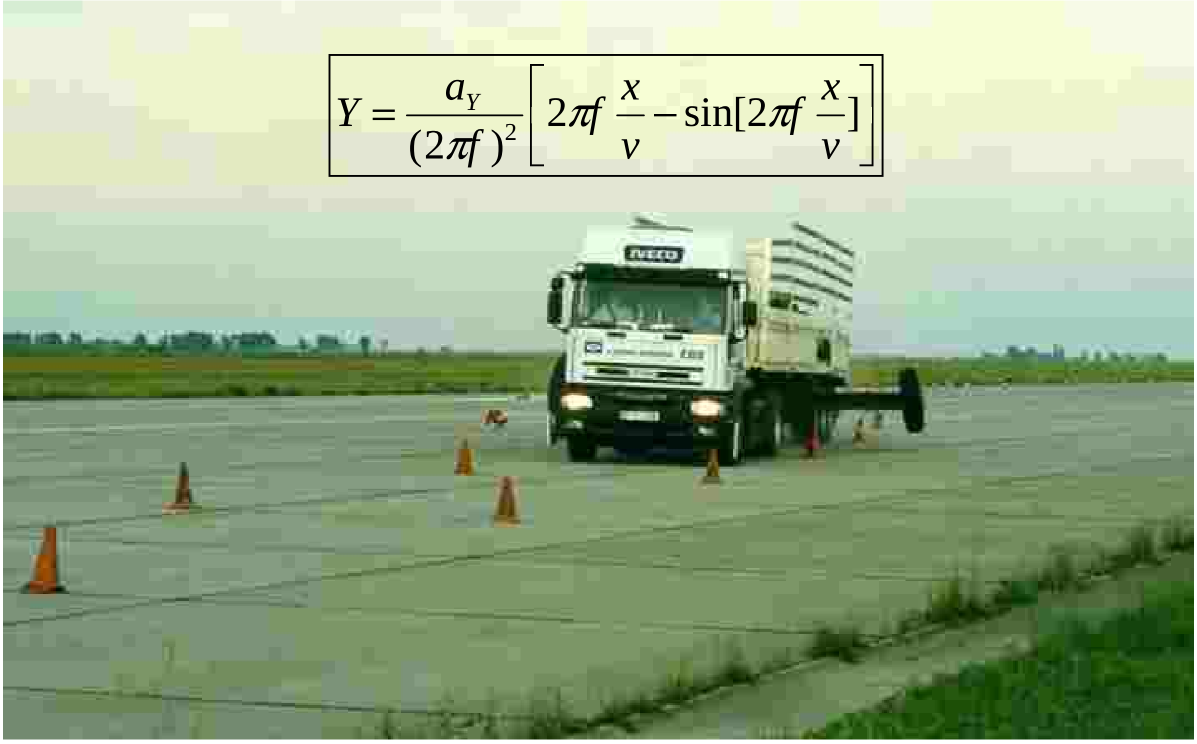


Figure 3: Path of single lane change (and formula) for the drive tests of KTI

4 RESULTS

The cornering stiffness of the wide base single tyre is higher than that of the dual tyres, see figure 4. This is the main reason for the more under-steering behaviour, which usually is said to be safer than over-steering, of for instance a single truck. This was also observed by drive tests carried out by Volvo [2]. The tendency to under- steering can also be observed for articulated vehicles.

From the simulation of the single lane change manoeuvre (and from the driving tests, too) it can be seen that the rearward amplification of the yaw velocity and the lateral acceleration are somewhat lower for the single tyres compared with the dual tyres on the drive axle. The difference of the rearward amplification of the lateral acceleration on it's maximum at 0,5 Hz is about 5%, the difference of the rearward amplification of the yaw velocity is much smaller and therefore neglectable. Variations in the spring base width obviously do not have a noticeable influence on the driving behaviour. Also the height of the centre of gravity do not change the described behaviour in general.

Most information can be derived from the stability simulation of driving into the J-turn.

Figure 5 shows possible vehicle reactions, which are mainly dependent of the centre of gravity height and tyre characteristics. In the simulation the velocity was increased step by step until one of the stability limits was reached. The maximum velocity and the maximum attainable lateral acceleration are the interesting parameters.

The driving radius is calculated by: square-velocity divided by centripetal acceleration.
The actual driving behaviour can be described by comparing the actual radius relative to the radius a vehicle would follow with a given steering angle without a lateral acceleration, that means driving with a speed of nearly zero. If the actual driven radius proves to be higher, the behaviour of the vehicle can be described as under- steering (safer) and if the radius gets smaller, the behaviour is called over- steering. The danger of jack-knifing is the result.
The maximum attainable lateral acceleration can be compared, too. It signifies a kind of resistance against roll- over. For the road trains (and trucks in the same kind) the following versions were examined, see figure 6. The spring base is adapted every time for the different tyres used.

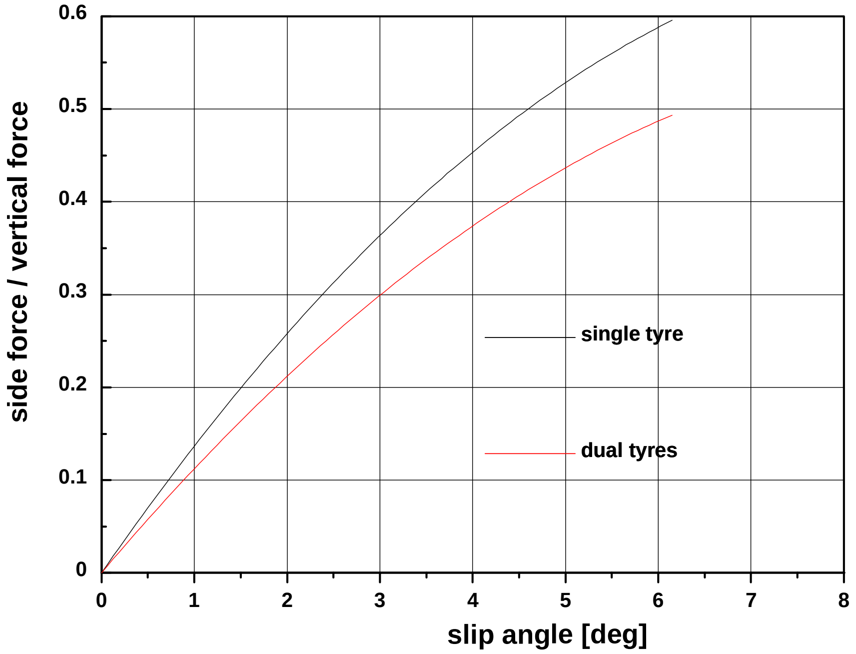
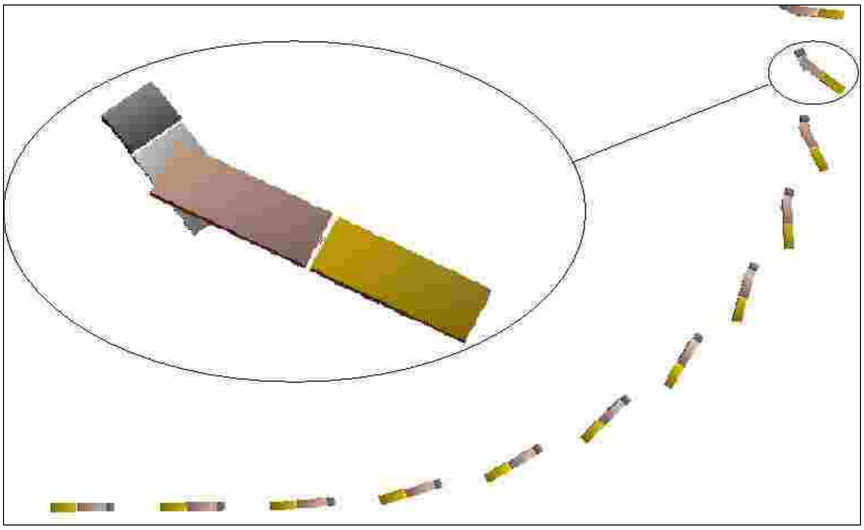
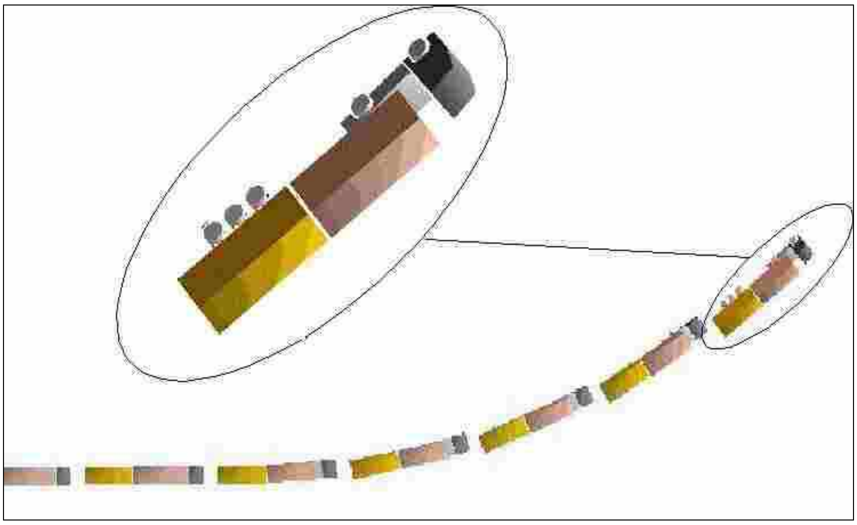


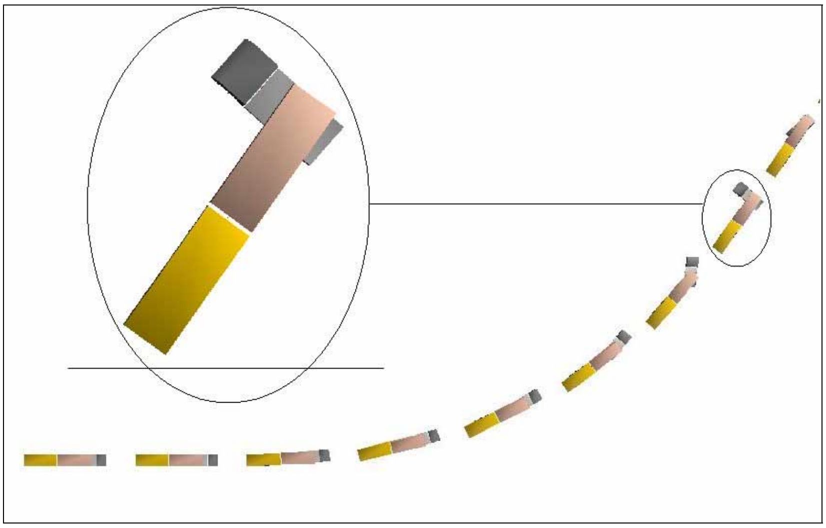
Figure 4: Cornering stiffness of wide base single and dual tyres in principal



Tractor semi-trailer going into skid



Tractor semi-trailer roll over



Tractor semi-trailer jack knifing

Figure 5: Unstable driving conditions for a unit (stability limits for J-turn simulation)

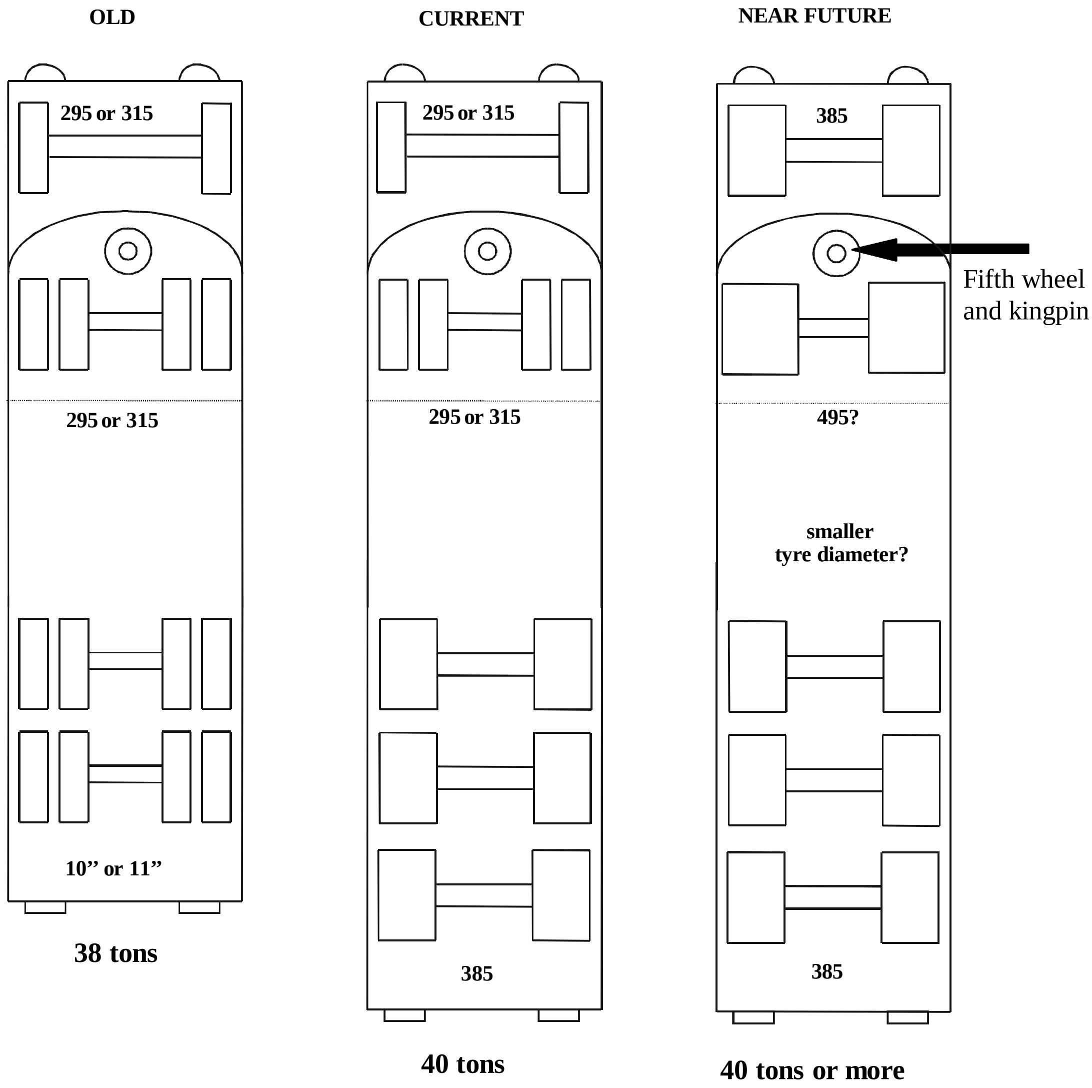


Figure 6: Old, current and future tyre combinations used for tractor semi-trailer combinations

For articulated vehicles there is no difference in the maximum attainable lateral acceleration. The attainable max. lateral acceleration is strongly dependent of the height of the centre of gravity. Increasing the height of the centre of gravity by 70 cm reduces the max. lateral acceleration to about 40%. Swinging loads hanging from the roof is the most dangerous loading condition. The attainable max. lateral acceleration is reduced to more than half of that attainable by the vehicle with low centre of gravity. The max. lateral acceleration is improved for the solo truck using wide base single tyres by about 10 %. This means a higher roll- over stability can be achieved, see figure 7.

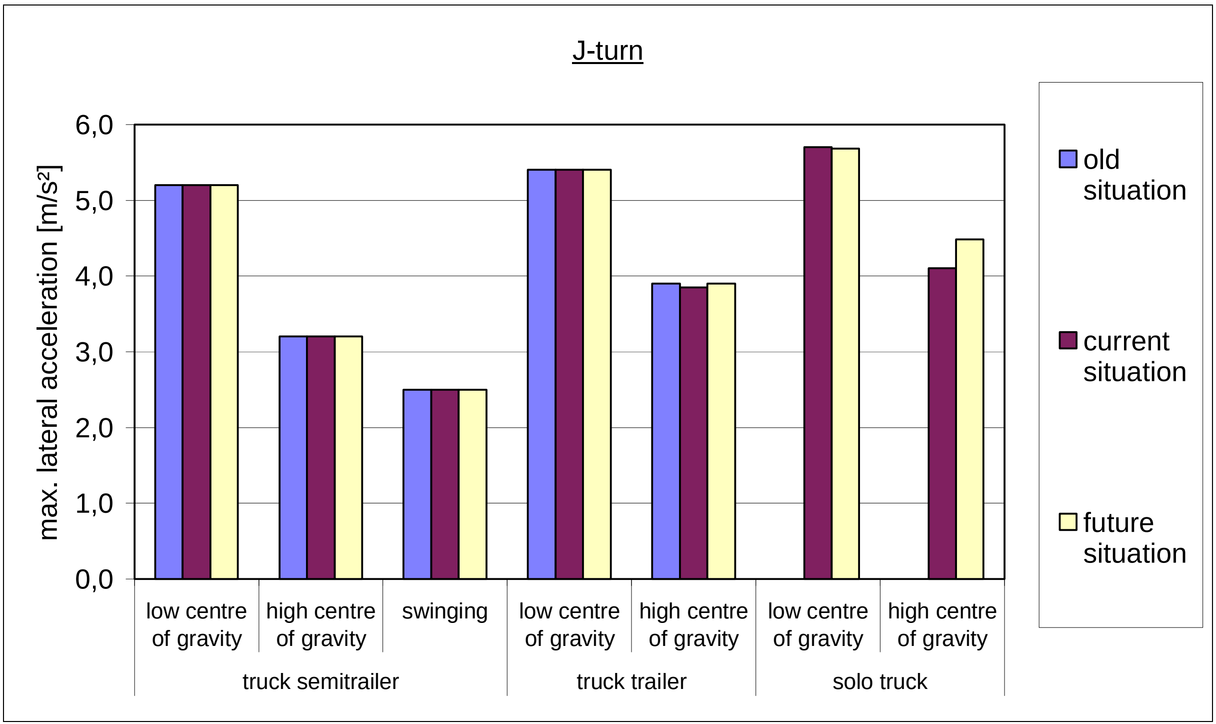


Figure 7: Max. lateral acceleration for different trucks and articulated vehicles with different CG heights

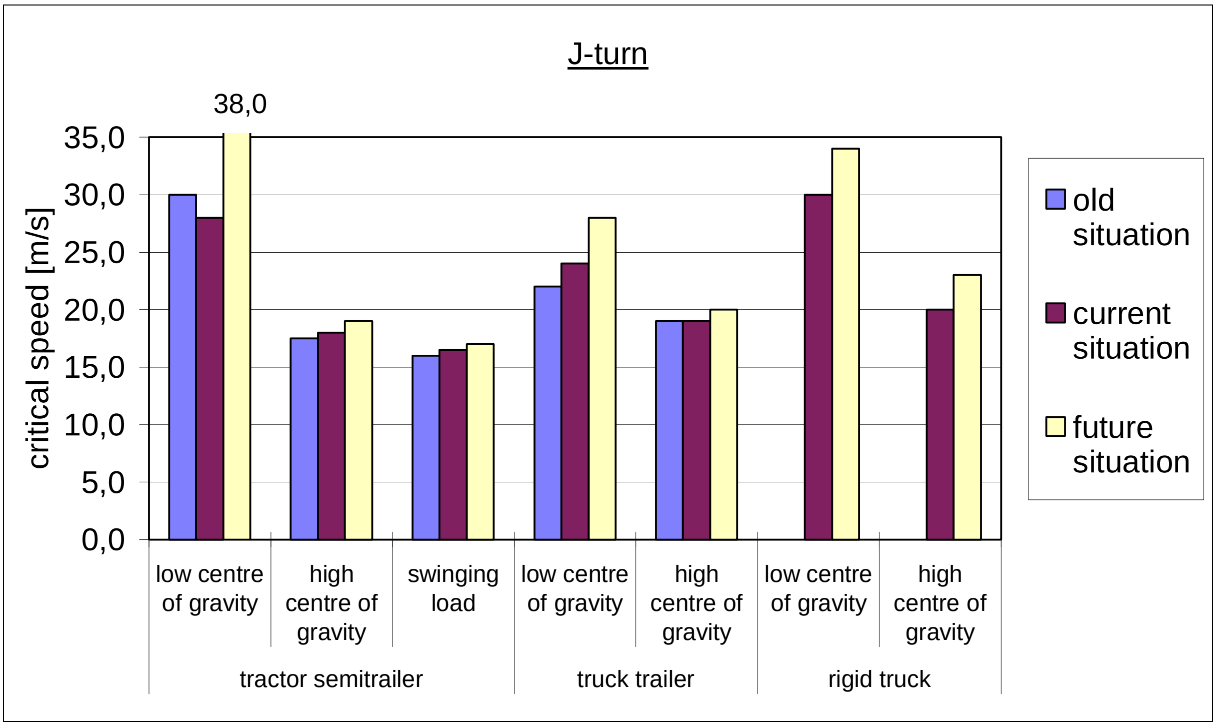


Figure 8: critical speed of trucks and units with different tyre combinations and CG heights

Figure 8 shows the results of the critical (max.) speed of trucks and units going into a J-turn. Trucks and units have a higher critical speed with the same lateral acceleration, if they are equipped with wide base single tyres. This means they have a (safer) more under-steering driving behaviour. This advantage is higher with the trucks and units having a lower centre of gravity. The critical speed for a single truck is about 10 % higher having wide base single tyres on the drive axle.

Another safety aspect is the vehicle behaviour in case of sudden tyre burst especially in a bend. This was studied by simulation, too. Most dangerous is a sudden tyre defect on the outer tyre of the drive axle. Only the 40 t tractor with semi- trailer was analysed. As soon as the tyre loses its pressure two effects will take place:

- The maximum transferable side force of a defect single tyre decreases rapidly, for a twin assembly only one tyre can transfer side forces.
- With a flat single tyre the wheel and the car body goes downwards, for a twin assembly one tyre has to carry half of the axle load alone, but the vehicle body moves down only a little bit.

Both effects were part of the simulation. The loss of tyre pressure was assumed to occure one second. The max. transferable side force for the single tyre was assumed to be 40 % relative to the intact tyre. For these parameters the critical speed and maximum lateral acceleration in case of the J-turn manoeuvre were calculated, see figure 9.

The over-steering driving behaviour, caused by a puncture damage of one of the dual tyres, changes into an (safer) under-steering behaviour, if a wide base single is used, (The change into higher lateral acceleration values for twin tyres indicate a smaller radius in the path). It has to be considered that a wide base single tyre has the disadvantage, that the roll over limit is considerably lower, for both low and high centre of gravity, if a tyre burst happens.

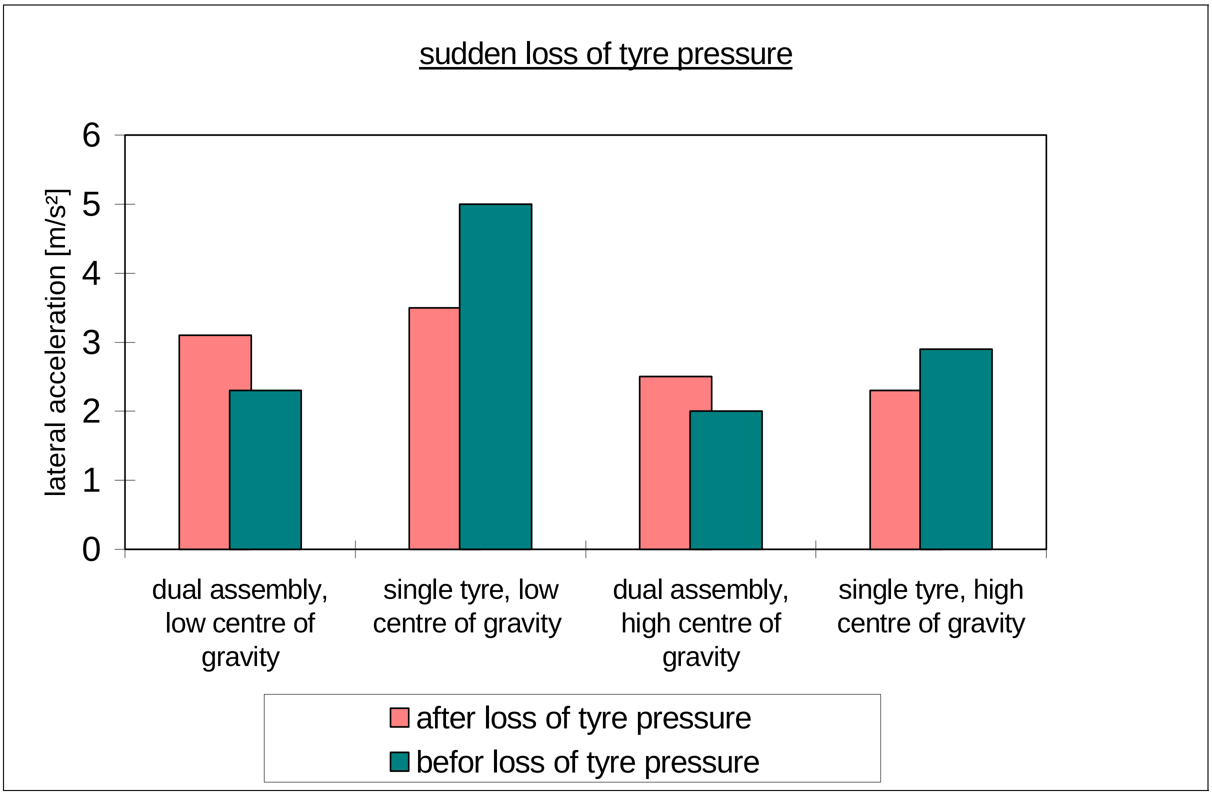


Figure 9: Max. lateral acceleration for a 40 t unit having a sudden tyre burst on drive axle in a J-turn

5 CONCLUSIONS AND FURTHER NON SAFETY EFFECTS

Wide base single tyres for drive axles of different manufacturers are in the market now and will probably replace the twin tyres used today. The driving behaviour of trucks and articulated vehicles was studied by computer simulation. Drive tests with the a 40 t unit with prototype single tyres on the drive axle were carried out to verify the simulation.

The following results were derived from the simulation: Alterations in driving behaviour and driving safety are mainly dependent on the tyre characteristics (cornering stiffness) of the tyre itself. The wide single tyres showed a higher level of lateral stiffness which was reflected by a higher degree of under-steering i.e. safer driving behaviour. This tendency is beneficial with regards to the steerability of a vehicle combination. The altered width of the spring suspension on the drive axle had no influence on the side-tilt stability of the vehicle combination. Only the solo truck profited from the higher roll stiffness of the rear axle, which means a lower danger of a roll-over accident. As far as the driving safety is concerned no factor spoke against using wide base tyres on the drive axle.
The investigation into the driving stability with defect tyres on the drive axle showed for the very seldom case of tyre defect in a bend (assuming 40% of the max. transferable side force for the flat tyre) no increased danger could be observed in the mathematical simulation when using wide base single tyres.
Later driving tests [2, 5] showed however the need of tyre run flat properties (e.g. supporting ring on the rim) to avoid jack-knifing of road trains. Also tyre pressure monitoring systems and electronic stability programs for the trucks are advised.

In addition to the described safety aspects some more advantages and disadvantages of wide base single tyres should be mentioned but without further explanations [4]:

- The rolling resistance of a single tyre is about 20 % less compared with twins. This leads to lower fuel consumption (about 2 % for a 40 t unit) and lower CO_2 emissions.
- A higher pay load (130-150 kg) can be realised.
- The tyre road noise is nearly equal for both tyre combinations.
- The road wear (rutting) is higher for single tyre equipped trucks, especially on secondary roads. This can be nearly compensated if the wider 385 size tyres are used on steering axles instead of the common 315 or 295 size.

6 LITERATURE

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